MATURITY-ASSOCIATED VARIATION IN FUNCTIONAL CHARACTERISTICS OF ELITE YOUTH TENNIS PLAYERS

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Abstract

Purpose.

To evaluate relationships among skeletal maturity, body size, and functional capacities of elite junior tennis players.

Method.

Participants were 88 elite British Junior tennis players (44 male; 44 female), 8-16 years of age (12.4±1.9 years). Skeletal age estimated maturty. Anthropometry, grip strength, countermovement jump, squat jump, forehand agility, backhand agility, Yo-Yo, 5m, 10m and 20m sprints were measured. Comparative analysis for each sex was performed, relating advanced maturers (Male: 15; Female: 29) to a combination of on-time and late maturers (Male: 29; Female: 31). ANCOVAs were used to determine absolute differences between male and female players and between the two maturity subgroups, with chronological age as the covariate.

Results.

Advanced maturity afforded male players advantages in absolute measures of grip strength, speed, upper and lower body power but not in acceleration, agility or aerobic endurance. Male players were significantly taller than females in the U13-U16 age group. Advanced maturity in female players afforded advantages in absolute measures of grip strength, agility and overhead power, but not in backhand agility, aerobic endurance or squat jump power.

Conclusion.

It is important that talent identification protocols consider the maturity of youth athletes to more satisfactorily address athletic potential rather than transient physical capabilities.

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Introduction

Contemporary tennis is characterized by dynamic, fast, attacking play (18), rapid exchanges punctuated by quick starts and stops, and repetitive overhead actions (15). Estimated work rate fluctuates between short periods of maximal intensity and longer periods of moderate to low intensity (15). Matches vary in duration between 90 minutes and 5 hours, and are affected by type of playing surfaces (25). Given the preceding general conditions of match play, a combination of functional capacities is required of players, although the exact combination of capacities has yet to be determined (24). Nevertheless, evidence supports the contention that functional capacities such as strength, power, speed, agility and endurance are necessary in order to compete at the highest levels (24, 39, 41, 45). The ability of youth players to produce consistently fast, accurate and powerful groundstrokes appear to be linked to success at this level (22). Functional capacities such as jump height, maximal strength of the dominant limb and agility have also been noted as good predictors of tennis performance (22, 44).

Functional capacities vary with growth and maturity. The impact of biological maturity on functional performance on youth in general and among youth athletes is well documented (4, 5, 14, 23, 32, 43, 46). Size and functional differences associated with variation in maturity status are most marked during adolescence (32, 35). Youth advanced in maturity have functional advantages compared to less mature chronological age peers, but the contrasts are more marked among adolescent males than females (6, 20, 32). Functional differences associated with maturity are to some extent transient as differences among youth of contrasting maturity are reduced and in some instances eliminated in late adolescence or young adulthood (1, 8, 27, 47).

Data addressing growth and functional capacities of youth tennis players in the context of biological maturity are limited (48). Youth tennis players tend to be, on average, taller and heavier than UK reference standards, during adolescence, though data on maturity status is limited (35, 38).

Given the physical and functional demands of tennis, it is likely that biological maturity might play a significant role in the selection and performance of youth players. Size, strength and power associated with advanced maturity, particularly during adolescence, can be advantageous. On the other hand, changes in body composition associated with early or advanced maturity in females (specifically, increases in absolute and relative fatness) may negatively impact some aspects of performance related to items in which the body is moved or projected through space as in runs and jumps.

The purpose of this investigation is to evaluate the functional capacities of elite youth tennis players relative to skeletal maturity. It specifically compares the functional capacities of players of contrasting maturity combined by competitive age groups, U10 through U12, and U13 through U16, and then evaluates the relationships between skeletal maturity and functional performances. It is hypothesized that both male and female players advanced in maturity will show greater strength and power compared to less mature peers of the same chronological age. Reviewing the limited data available for adolescents, no differences in speed, agility and endurance among maturity groups of tennis players are hypothesized

Methods

Participants

The sample includes 88 elite British youth tennis players (44 Male, 44 Female) who represented the top eight players in the GB National rankings in their respective age groups (U10, U11, U12, U13, U14, U15 and U16). Participants in a competitive age category might be of the upper age limit for the group, e.g., a 12 year old could compete in the U12 category. In 16 instances, a top eight player was unable to attend the National Training Camp for assessment. In these cases, the next highest ranked player within the respective age group was invited and attended the Camp (6 male; 10 female), in the remaining cases no additional player was invited. Based on self-ascribed ethnicity, 73 players identified as Caucasian (males 40; females 33), 6 as mixed race (males 2; females 4), 7 as Black (males 1; females 6), and 2 as Indian (male 1; female 1). It should be noted that the participants in the current study are the same participants from an earlier publication examining the anthropometric characteristics of elite youth tennis players (38).

The study was approved by the Research Ethics Approval Committee for Health at the lead author's host University and the Lawn Tennis Association. Written assent and consent was obtained from both participants and parents/guardians.

Procedures

Data were collected at a three-day camp at the National Training Centre in Roehampton, London. Participants arrived the day before assessment. Chronological age (CA) was measured as the difference between date of birth and date of a radiograph of the left hand-wrist, which was taken for the purpose of assessing skeletal maturity. Players ranged in CA from 8.87 to 16.78 years; the mean of the sample was 12.44±1.90 years. The radiograph was taken by an onsite certified technician. The Fels method for estimating skeletal age (SA) was used (42). The Fels method uses a variety of indicators and ratios that are entered into a software program (Felshw 1.0) along with sex and CA of the individual to estimate SA and its associated standard error. The latter is not provided by other methods of assessment (32). Participants provided assent/consent for the hand-wrist radiograph.

All hand-wrist films were assessed by a trained technician and an experienced independent assessor. The mean difference between assessors was -0.07 years, with a relative technical error of 1.22% and an intraclass correlation of r=.99 (C.I. 95% = .99-1.00).

Relative SA for each participant was calculated as the difference between SA and CA (SA minus CA). Participants were classified as late (SA younger than CA by >1.0 year), on time (average, SA within ±1.0 year of CA), or early (SA older than CA by >1,0 year) maturing (31). No players were skeletally mature.

Height and weight were measured following standardized procedures (34), using a calibrated Harpenden stadiometer and a Marsden Weighing Company DP2400 BMI Indicator scale to the nearest 0.1cm and 0.1kg respectively. Participants were barefoot, wore a t-shirt and shorts and removed all headgear.

After a standardised warm-up (9), several functional measures were taken by the same trained technician in the following sequence: strength, speed, power, agility and endurance. All functional measures were performed on the indoor tennis courts located at the UK National Tennis Centre. Players were afforded a minimum of one-minute rest between efforts. Right and left handgrip strength, running speed, the countermovement jump, and the forehand, backhand and overhead medicine ball throw were measured in all age groups. Other measures were limited to specific age groups as per the National Governing bodies physical testing protocol. Agility on the hexagon test was measured among U10 and U12 players, whilst forehand and backhand agility, squat jump and the Yo-Yo intermittent recovery test were measured among U14 and U16 players. Three attempts were given for each test, and the best performance was retained for analysis (11).

Right (RHGS) and left handgrip strength (LHGS) were measured to the nearest 0.5 kg with a Takei A5401 digital handgrip dynamometer to the nearest. The grip of the dynamometer was adjusted for each participant. From a raised arm position, the player lowered his/her arm through a 180 degree arc for approximately three seconds, while maximally gripping the dynamometer. The digital reading was recorded at the end of the movement. The testing sequence was R, L, R, L, R, L.

Linear running speed was measured at 5m, 10m and 20m intervals with electric timing gates (Smartspeed, Fusion Sport pte, Australia). The 5m time provided an indication of acceleration. The player lined up in the tennis ready position 30cm behind the start line and in his/her own time sprinted as fast as possible through the three electronic timing gates, not slowing down as he/she ran through the 20m gate.

Lower body power was measured with the squat jump (SJ) and countermovement jump (CMJ) using a Yard-Stick (Perform Better UK). For the SJ, the player dropped into a squat position with their dominant arm raised overhead and reaching height was measured in this position. Without any further downward movement, the player then jumped with both legs as high as possible. In the CMJ, reaching height while standing was initially measured. The player then performed a rapid dip and drive, swung their arms and jumped up as high as possible. In both jumps, the player aimed to displace the plastic vanes of the Yard-Stick at the height of the jump. The distance between reaching height and jumping height was calculated to the nearest 1cm for each jump.

Upper body power was measured with medicine ball (1 kg) throws from the forehand (FHMBT) and backhand (BHMBT) sides as well as overhead (OHMBT). For FHMBT, the player stood side on in a closed stance position at the baseline. Stepping backwards while simultaneously rotating the arms and trunk to the forehand side, the player then stepped forward to explosively throw the medicine ball as far as possible (see image 1). The BHMBT utilized the same protocol except that the test was performed from the backhand side. The OHMBT required the player to stand in the serve position at the baseline. The player elevated and flexed their arms so that the ball was held behind the head. Simulating the tennis serving action, the player propelled the ball forward as far as possible. Leg flexion/extension and trunk/shoulder rotation were permitted but not a step forward (see image 2). Each throw was measured to the nearest 0.01 meter.

The Hexagon Agility test required the player to stand facing forwards, in the middle of a hexagon measuring 60cm per side and with 120-degree angles. With feet together and hips facing forward throughout the test sequence, participants hopped forwards and backwards in a clockwise manner over each of the six sides of the hexagon. Time to complete three rotations was recorded to the nearest 0.1 second (Fastime 0 Stopwatch). A penalty of 0.5 seconds was given each time the player touched a line and a 1.0 second penalty was given if the player failed to follow the correct sequence. A practice attempt was given prior to the three trials.

The Forehand Agility test (FAT) required the player to line up 30cm off the centre line of the baseline, facing the tennis court and in the tennis ready position. After initiating the test with a split step, the player turned and sprinted through electronic timing gates (Smartspeed, Fusion Sport pte, Australia), positioned perpendicularly on the centre line of the baseline, towards the inside tramline on the forehand side. After touching a cone placed at the juncture of the inside tramline and baseline, the player turned and sprinted back through the timing gate. Time was recorded to the nearest 0.1 second. The Backhand Agility test (BAT) was identical with the exception that it was performed on the backhand side.

The Yo-Yo Intermittent Recovery test (YYIRT) was the measure of aerobic endurance. The player repeatedly ran 20m shuttle runs with 10 seconds recovery after each 40m (2 x 20m). The pace of the shuttles was set by an audio metronome and progressively increased. The score was the total distance covered before the player was unable to maintain the required pace (37).

Statistics

Due to the small sample sizes, players were combined into two age groups for analysis, U10 through U12, and U13 through U16. Descriptive statistics were calculated for all variables for male and female players in each age group and also for two maturity subgroups within each age group. The small group of late maturing players (5 males, 2 females) was combined with the on-time group; hence, players classified as late + on time players were compared to early maturing players within each combined age group.

A series of univariate ANCOVAs with CA as the covariate was used to compare sex differences in size, SA and functional capacities across the two combined age groups (Table 1).

Given the limited numbers of players across the age range, subsequent analyses were based upon the total samples of male and females, respectively. Partial correlations controlling for age were calculated to examine the association between skeletal maturity (SA/CA ratio) and each of the functional performances.

A series of univariate ANCOVAs with CA as the covariate was used to compare the two maturity groups in the total samples of male and female players: combined late + on time versus early maturing groups.

Due to the limited sample size and the exploratory nature of the study, the criteria for statistical significance was set at $p<0.1$. This decision was made on the basis that it was more important to avoid type 1 over type 2 errors (26), i.e., it was important not to overlook factors that may explain variance in functional performance that did not achieve statistical importance due to limited sample sizes. It should also be noted that effect size, which reflects the magnitude of an association or difference, is also reported (see Table 1). Effect size is often viewed as more meaningful than significance (8, 28), due to the fact that significance is greatly influenced by sample size.

Results

Descriptive statistics (means and standard deviations) for all variables of male and female tennis players in the U10-U12 and U13-U16 age groups and results of the univariate analyses of covariance are summarized in Table 1. Among U10-U12 players, girls are significantly advanced in SA per se and in skeletal maturity expressed as SA minus CA. Otherwise, youth tennis players of both sexes do not differ in body size and functional performances with the exception of BAT and SJ; girls performance significantly better than boys. Among U14-U16 players, only SA, SA minus CA and weight do not differ between males and females. Boys perform significantly better than girls in all functional performance tests.

All functional performances improve, on average, from the younger to older groups of male players. On the other hand, age group comparisons are more variable in female players. Grip strength and power (CMJ, medicine ball throws) improve, on average, from the younger to older groups of players (significant for FMBT, BHMBT in both sexes). Power measured in the SJ and endurance in the YYIRT are less in the older than younger female players. Sprint speed and agility show negligible differences between age groups, with the exception of FAT, which differed significantly between younger and older males.

Among U10-U12 players, differences between males and females in SA, SA-CA, SJ and BAT have moderate to large effect sizes (d = .30-.60). The effect size for differences between U14-U16 males and females in body size, SA, SA-CA and functional performances exceed convention for a large effect ($d \geq .60$) (13).

Descriptive statistics for functional performances of contrasting maturity groups within each age group of males and females are summarized in Table 2. Among U10-U12 boys, more mature players perform better, on average, in the strength (grip) and power (jumps, medicine ball throws), while performances in the sprints and agility tests show negligible differences. Corresponding comparisons among U10-U12 girls are more variable. Players advanced in maturity perform better, on average, in grip strength, CMJ, FAT and BAT, while players delayed in maturity perform somewhat better, on average, in the Hexagon, SJ and medicine ball throws. The sprints and YYIRT do not differ between maturity groups of girls U10-U12 years.

Among older players, boys advanced in maturity perform better in grip strength, CMJ, SJ, and medicine ball throws, while differences in the sprints, agility and YYIRT are negligible between maturity groups of boys U14-U16 years. Differences between U14-U16 female players of contrasting maturity are small or negligible for the sprints, agility, jumps, forehand and backhand medicine ball throws, and the endurance run; players advanced in maturity perform better, on average, in grip strength and overhead medicine ball throw.

Partial correlations between skeletal maturity, reflected in the SA/CA ratio, and the functional performances in the combined samples of younger and older players within each sex are summarized in Table 3. Overall, correlations range from low to large. Among male players, correlations between maturity and grip strength are positive and generally moderate (0.21, 0.33) and moderate to large in medicine ball throws (0.38 to 0.64). Corresponding correlations among female players are positive and moderate for grip strength (0.41, 0.41) but are more variable for the medicine ball throws (0.19 to 0.51). Other correlations between maturity and performances in male players are positive and low, 0.00 to 0.22. Corresponding correlations for female players are more variable, low for the sprints (0.08 to 0.20), jumps (0.10, 0.13) and YYIRT (-0.22), but higher for BAT (0.34) and FAT (0.72). The Hexagon test is limited to U10-U12 players and the correlation between performance and maturity is low in boys (0.16) but higher in girls (0.39).

Allowing for the small sample sizes in the U10-U12 and U14-U16 groups, the samples were combined in each sex to further evaluate the influence of variation in maturity on the functional performances. Players classified as late + on time and early by the SA-CA difference were compared in the total samples of male and female players, respectively. Age-adjusted means and standard errors based on univariate analyses of covariance are summarized in Table 4. Upper body strength (RHGS, LHGS), speed (10m and 20m sprints), lower body power (CMJ) and upper body power (FHMBT, BHMBT, OHMBT) are significantly better among male players advanced in skeletal maturity. Acceleration (5m sprint), agility (Hexagon, FAT, BAT), power (SJ) and endurance (YYIRT) do not differ between male players of contrasting maturity. Among female players, only upper body strength (RHGS, LHGS), agility (FAT) and overhead power (OHMBT) differ significantly between players of contrasting maturity. The other functional performances – acceleration (5m sprint), speed (10m and 20m sprints), agility (Hexagon, BAT), lower body power (CMJ, SJ), upper body power (FHMBT, BHMBT, OHMBT) and endurance (YYIRT), do not differ between maturity groups.

Discussion

The results highlight the performance advantages of advanced skeletal maturity among elite male youth tennis players. The advantages are especially apparent in measures of upper body strength, speed and power, although do not account for difference in body size. These observations are generally consistent with the literature for adolescent males (32). Corresponding observations for female youth tennis players are lacking. Studies of youth athletes in other sports generally indicate similar maturity-related trends but there is also variation. Soccer players 13-15 years advanced in pubertal status performed better in a 30m sprint, CMJ and YYIRT (33). In a sample of elite soccer players 13.5±0.4 years, early maturers (Greulich-Pyle SA) performed better than less mature players in the CMJ, sprints (10m, 20m, 40m), and leg strength; in contrast, the contrasting maturity groups did not differ in peak VO2 (12). On the other hand, observations for youth soccer players of contrasting maturity status (Fels SA) 11-12 and 13-14 years were more variable (17). First, players of contrasting maturity (based on Fels SA) did not differ in speed and agility; second, CMJ and SJ performances did not differ among players 11-12 years but were better among early maturing players 13-14 years; and third, late maturing players performed better on the YYIRT.

On the other hand, performance advantages associated with advanced skeletal maturity were less apparent among the elite female players. Advantages were limited to upper body strength, forehand agility and overhead power. These observations were consistent with limited comparative data for female tennis players (48). In the study of U14 female tennis players, early maturing (determined by the Biological Maturity Identification Questionnaire) girls outperformed on-time and late maturing peers on measures of grip strength and upper body power, whereas the players in the contrasting maturation groups did not differ in several motor performance tests (48). Among adolescent girls in general, a positive relationship between maturity status and strength is apparent, while limited data for performances of adolescent girls of contrasting maturity indicates inconsistent trends from task to task and across age with considerable overlap among groups (28, 32). It is difficult, however, to generalize from the general population of adolescent girls to elite youth athletes in a specific sport.

The discrepancy in observations for female tennis players and the general population of adolescent girls is likely related in part to the tests compared. Specific functional tests were used with the tennis players (FAT, BAT, FHMBT, BHMBT, OHMBT, YYIRT), while general motor performance tests (Sit and Reach, Arm Pull, Bent Arm Hang, Shuttle Run), were used in the other studies (32). A related factor may also be body composition. The greater absolute and relative fat mass of early maturing girls may negatively influence the performances in which the body is moved or projected through space (runs, jumps) as suggested in previous research (2, 7).

Furthermore, rapid changes in relative limb length, experienced during the adolescent growth spurt, may negatively influence balance and co-ordination of players advanced in maturity, therefore adversely affecting their speed and agility scores. These observations are in line with other sports that demand a combination of physical components in addition to a particular skill set (16, 36).

In contrast with results from this study, research examining peak VO_2 in relation to skeletal maturity found that adolescents who were advanced in maturity demonstrated a significantly higher absolute VO_2 value than their less mature peers (49). However, when examining peak VO_2 relative to body mass, previous research has found no difference between differing maturity groups in females (7), or has indicated that late maturers return higher values in both sexes (49).

Talent identification protocols generally include general and sport-specific assessments of performance. As such, youth advanced in maturity will likely have a performance advantage compared to less mature peers in some performances, especially those related to strength and power. It therefore appears that advanced maturers possess a distinct advantage over their less mature peers when participating in these protocols. As such, in sports where larger body size is perceived as a requisite for successful performance, the prevalence of youth advanced in maturity is higher (6). Larger, stronger youth may perform better, but they also receive preferential treatment from adults and often perceive themselves as being better (10). There is a need for further study of adults (coaches) and the sport selection and training environment in general (30).

Variation in maturity between the sexes and among individuals is considerable. SA provides an indicator of maturity. Related factors not considered in this study are maturity timing (age at peak height velocity, age at menarche) and the tempo or rate of maturity. Assessment of maturity timing requires longitudinal observations (29). Talent Identification protocols indicate size, maturity and performance at a single point in time and these characteristics may not accurately reflect the potential for further development of players (3). Furthermore, late maturing individuals eventually catch-up and often surpass their advanced maturing peers in late adolescence and young adulthood, thus reducing and/or eliminating anthropometric and performances advantages of early maturity during adolescence (8, 27, 40, 47). The trends in later adolescence needs more attention in talent identification protocols.

The findings in this study have several implications for tennis. First, the modern game requires powerful serves, swift movements and rapid exchanges of groundstrokes, all of which require components of strength and power. Therefore those advanced in maturity possess a distinct physical advantage over their less physically mature peers. Success on the court will positively influence ranking, enhancing the ability of those more physically mature to obtain the necessary financial support to receive expert coaching and sport science support. Incorporating bio-banded (biological banded age groups) competitions alongside regular age group competitions may account for some of these differences, leveling the playing field. Bio-banded competitions group players according to their maturational status (early, on-time, late) within an age group, rather than according to chronological age. This enables players to be matched up with their respective physical competitors, allowing players of differing maturity the ability to develop a full complement of skills required to compete at the elite level. Bio-banding might also used in the process of evaluating both physical and functional capacity among youth tennis players. That is, players' performances could be compared against both age and maturity derived standards. In support of this contention, research conducted with German youth footballers demonstrated that while the youngest players demonstrated the poorest absolute performance within their respective age groups, their performances were markedly superior to their older peers when judged relative to developmental norms (50). This suggest that the youngest and/or least mature players must possess physical, functional, technical or psychological abilities that are above the developmental norms in order to remain competitive with their age groups; a principle that is in accordance with Gibbs and colleagues underdog hypothesis (21).

Second, tennis is a game that requires a combination of speed, strength, power, agility, flexibility and cardiorespiratory capacity (25), in addition to technical and tactical expertise and mental fortitude. Therefore, any aspiring tennis player wishing to compete at the professional level needs to possess a well-developed physical fitness profile (41). This requires many hours of dedicated and specific training often starting at a very young age. The understanding of how best to develop athletic potential in children and adolescents has improved over the last decade (3), with increased awareness of the effects of biological maturity on performance (19). That said, current practice does not routinely accommodate for players of differing maturity and current models still utilize CA classification that does not account for the large variability between individuals (20). Whilst additional research is needed to explore program specifics, it is clear from these findings that a physical pathway needs to be developed that accommodates for players of differing maturity. This will hopefully allow each player to be developed as an individual, rather than prescribing to the notion that players should work on the same physical attributes during certain time periods.

The study is limited to a relatively small, cross-sectional sample of elite tennis players from the UK. The results may therefore not apply to more general samples of tennis players and to elite tennis players from other countries. Furthermore, training volume and experience were not considered. There is a need to longitudinally follow the growth and performance trajectories of youth players through adolescence into young adulthood. There is also a need to carefully consider the characteristics of players who drop out of, or who are systemically eliminated by the sport.

In conclusion, this study examined maturity associated differences in the functional capacity of elite British youth tennis players. The findings of this study highlight the advantage that youth male tennis players advanced in maturity possess in measures of upper body strength, speed and power. Whilst the effects are less apparent in female tennis players, those advanced in maturity are afforded an advantage in upper body strength, forehand agility and overhead power. This has implications in both the identification and training of elite youth athletes.

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Conflicts of Interest and Source of Funding

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Appendices

Table 1. Descriptive statistics for chronological age, body size, skeletal age, and functional performances of tennis players by sex within age groups.

	U10 – U12			U13 – U16		
	Male *n = 27*	Female *n = 27*	*Cohen's d*	Male *n = 17*	Female *n = 17*	*Cohen's d*
	M±SD	M±SD		M±SD	M±SD	
CA (yrs)	11.2 ± 0.92	11.1 ± 1.1	0.20	14.4 ± 1.0	14.6 ± 0.9	-0.20
Fels SA (yrs)	11.1 ± 1.52	11.6 ± 1.3	-0.33[a]	15.5 ± 1.3	15.0 ± 1.7	0.28
SA-CA	-0.2 ± 1.04	0.5 ± 0.9	-0.71[a]	1.1 ± 0.9	0.5 ± 1.3	0.58
Height (cm)	149.9 ± 0.1	150.7 ± 0.1	-0.12	173.1 ± 0.1	164.7 ± 0.1	1.13[a]
Weight (kg)	40.1 ± 6.8	40.3 ± 7.8	-0.04	60.6 ± 9.0	58.7 ± 7.8	0.23
BMI (kg/m^2)	17.7 ± 1.8	17.6 ±1.6	0.08	20.1 ± 1.9	21.6 ± 1.9	-0.75[a]
RHGS (kg)	23.9 ± 5.3	23.8 ± 7.0	0.02	40.0 ± 9.4	34.1 ± 5.7[3]	0.76[a]
LHGS (kg)	21.2 ± 4.8	20.0 ± 5.8	0.22	38.5 ± 9.5	31.2 ± 5.1[3]	0.97[a]
5m Sprint (s)	1.20 ± 0.07	1.19 ± 0.06	0.15	1.06 ± 0.05	1.18 ± 0.07	-1.97[a]
10m Sprint (s)	2.06 ± 0.10	2.05 ± 0.08	0.11	1.85 ± 0.09	1.99 ± 0.11	-1.39[a]
20m Sprint (s)	3.59 ± 0.93	3.60 ± 0.15	-0.02	3.25 ± 0.16	3.47 ± 0.16	-1.38[a]
Hexagon (s)	11.80 ± 0.93[1]	11.74 ± 0.98[2]	0.03	NA	NA	NA
FAT (s)	2.46 ± 0.06[5]	2.39 ± 0.05[4]	1.27	2.26 ± 0.11	2.36 ± 0.09	-1.00[a]
BAT (s)	2.54 ± 0.06[5]	2.47 ± 0.07[4]	1.07[b]	2.36 ± 0.10	2.45 ± 0.10	-0.90[a]
CMJ (cm)	39.0 ± 5.4	40.3 ± 6.4	-0.23	50.2 ± 7.0	41.9 ± 5.4	1.33[a]
SJ (cm)	36.2 ± 2.5[5]	38.1 ± 5.3[4]	-0.47[b]	41.2 ± 5.9	36.1 ± 5.0	0.95[a]
FHMBT (m)	10.6 ± 1.5	10.0 ± 1.9	0.35	15.9 ± 2.0	12.7 ± 1.4	1.87[a]
BHMBT (m)	9.9 ± 1.3	9.3 ± 2.0	0.36	15.6 ± 2.2	12.1 ± 1.2	1.97[a]
OHMBT (m)	7.9 ± 1.3	7.2 ± 1.6	0.50	11.7 ± 2.5	10.0 ± 1.5	0.82[a]
YYIRT (m)	1336 ± 231[5]	1286 ± 173[4]	0.25	1736 ± 329	1065 ± 223	2.39[a]

[1]n=22, [2]n=20, [3]n=16, [4]n=7, [5]n=5

Significant differences between sexes ([a]p < 0.05; [b]p < 0.10)

CA: Chronological Age, SA-CA: Skeletal Age – Chronological Age, BMI: Body Mass Index, RHGS: Right Hand Grip Strength, LHGS: Left Hand Grip Strength, FAT: Forehand Agility Test, BAT: Backhand Agility Test, CMJ: Counter Movement Jump, SJ: Squat Jump, FHMBT: Forehand Medicine Ball Throw, BHMBT: Backhand Medicine Ball Throw, OHBMT: Overhead Medicine Ball Throw.

Table 2. Descriptive statistics for functional performances of youth tennis players by skeletal maturity status in two combined age groups.

	U10 – U12						U13 – U16					
	Male			Female			Male			Female		
	F	Late & On-Time *n = 22*	Advanced *n = 5*	F	Late & On-Time *n = 19*	Advanced *n = 8*	F	Late & On-Time *n = 7*	Advanced *n = 10*	F	Late & On-Time *n = 12*	Advanced *n = 5*
		M±SD	M±SD		M±SD	M±SD		M±SD	M±SD		M±SD	M±SD
RHGS (kg)	.24	23.70 ± 5.03	24.54 ± 6.78	5.02*	22.92 ± 6.78	25.71 ± 7.66	3.31*	36.80 ± 8.58	42.17 ± 9.73	2.52	33.47 ± 6.12	35.83 ± 4.56[b]
LHGS (kg)	.49	20.92 ± 4.53	22.26 ± 6.54	7.10*	19.03 ± 4.79	22.19 ± 7.60	10.31*	32.94 ± 7.45	42.40 ± 9.03	1.21	30.86 ± 5.11	32.03 ± 5.70[b]
5m Sprint (s)	.13	1.20 ± .08	1.19 ± .04	.05	1.19 ± .06	1.20 ± .06	3.92**	1.08 ± .04	1.05 ± .05	.46	1.18 ± .07	1.16 ± .07
10m Sprint (s)	1.48	2.07 ± .10	2.01 ± .05	.09	2.05 ± .08	2.05 ± .09	2.71	1.87 ± .07	1.83 ± .10	1.56	2.01 ± .09	1.96 ± .14
20m Sprint (s)	2.81	3.61 ± .16	3.50 ± .06	.05	3.60 ± .14	3.61 ± .18	4.59*	3.30 ± .11	3.21 ± .18	.76	3.49 ± .14	3.44 ± .20
Hexagon (s)	.14	11.84 ± 1.04[f]	11.65 ± .37	1.17	11.55 ± .93[e]	12.20 ± 1.04[d]	NA	NA	NA	NA	NA	NA
FAT (s)	1.73	2.46 ± .06[c]	NA	7.37**	2.41 ± .04[c]	2.33 ± .04[a]	1.25	2.22 ± .12	2.28 ± .10	6.26*	2.39 ± .09	2.30 ± .07
BAT (s)	NA	2.54 ± .06[c]	NA	6.76**	2.49 ± .07[c]	2.42 ± .03[a]	.12	2.35 ± .06	2.37 ± .12	.35	2.45 ± .11	2.43 ± .06
CMJ (cm)	1.63	38.55 ± 5.15	40.80 ± 6.83	1.43	39.79 ± 6.15	41.63 ± 7.31	4.03**	47.43 ± 4.39	52.10 ± 8.03	.00	42.00 ± 4.88	41.60 ± 7.16
SJ (cm)	NA	36.20 ± 2.49[c]	NA	.81	38.60 ± 6.07[c]	37.00 ± 4.24[a]	1.40	40.14 ± 2.19	42.00 ± 7.56	.03	35.92 ± 4.96	36.40 ± 5.59
FHMBT (m)	2.16	10.49 ± 1.52	11.00 ± 1.54	.83	10.06 ± 1.70	9.85 ± 2.49	20.24*	14.38 ± 1.40	17.03 ± 1.68	.56	12.67 ± 1.46	12.81 ± 1.18
BHMBT (m)	2.87	9.83 ± 1.32	10.44 ± 1.27	.72	9.41 ± 1.75	9.14 ± 2.57	18.41*	13.86 ± 1.63	16.82 ± 1.76	.37	12.02 ± 1.19	12.14 ± 1.35
OHMBT (m)	1.33	7.81 ± 1.34	8.30 ± 1.37	.31	7.21 ± 1.26	7.04 ± 2.38	11.89*	10.28 ± 1.93	12.61 ± 2.45	7.60	9.58 ± 1.37	10.87 ± 1.68
YYIRT (m)	NA	1336 ± 231[c]	NA	.19	1288 ± 159[c]	1280 ± 283[a]	.03	1760 ± 281	1720 ± 373	.00	1068 ± 222	1056 ± 251

[a]n=2, [b]n=4, [c]n=5, [d]n=6, [e]n=14, [f]n=17

Significant difference between maturity groups ($^{*}p < 0.05$; $^{**}p < 0.10$)

RHGS: Right Hand Grip Strength, LHGS: Left Hand Grip Strength, FAT: Forehand Agility Test, BAT: Backhand Agility Test, CMJ: Countermovement jump, SJ: Squat Jump, FHMBT: Forehand Medicine Ball Throw, BHMBT: Backhand Medicine Ball Throw, OHMBT: Overhead Medicine Ball Throw, YYIRT: Yo-Yo Intermittent Recovery Test.

Table 3. Partial correlations (one tailed) between functional performances and skeletal age in youth British tennis players.

Functional Performance Tests	SA/CA	
	Male *n = 41*	Female *n = 40*
RHGS (kg)	.21	.41**
LHGS (kg)	.33*	.41**
5m Sprint (s) [A]	.12	.08
10m Sprint (s) [A]	.17	.15
20m Sprint (s) [A]	.22	.20
Hexagon	.16[b]	.39[a]
FAT (s) [A]	.04[b]	.72[c]***
BAT (s) [A]	.22[b]	.34[c]
CMJ (cm)	.04[b]	.13[c]
SJ (cm)	.00[b]	.10[c]
FHMBT (m)	.61[b]**	.35
BHMBT (m)	.64[b]***	.19
OHMBT (m)	.38[b]*	.51[c]**
YYIRT (m)	.12[b]	-.22[c]

*Significant association between skeletal maturity and functional performance tests (*p<0.05; ** p< 0.01; ***p < 0.001)*

[a]n = 17, [b]n = 19, [c]n = 21

[A]Signs for the timed performances were inverted since a lower time reflects a better performance.

RHGS: Right Hand Grip Strength, LHGS: Left Hand Grip Strength, FAT: Forehand Agility Test, BAT: Backhand Agility Test, CMJ: Countermovement Jump, SJ: Squat Jump, FHMBT: Forehand Medicine Ball Throw, BHMBT: Backhand Medicine Ball Throw, OHBMT: Overhead Medicine Ball Throw, YYIRT: Yo-Yo Intermittent Recovery Test.

Table 4. Adjusted means and standard errors for functional capacities of youth tennis players by maturity status-groups within sex.

Functional Performance Tests	MALE			FEMALE		
		Late + On-Time n = 29	Advanced n = 15		Late + On-Time n = 31	Advanced n = 29
	F	M ± SE	M ± SE	F	M ± SE	M ± SE
RHGS (kg)	3.79**	26.87 ± .98	36.29 ± 1.39	6.22	27.00 ± .89	29.08 ± 1.43[d]
LHGS (kg)	11.47*	23.82 ± 1.01	35.69 ± 1.43	7.76*	23.61 ± .76	25.47 ± 1.23[d]
5m Sprint (s)	2.48	1.17 ± .01	1.09 ± .02	.23	1.19 ± .01	1.18 ± .02[c]
10m Sprint (s)	4.61*	2.02 ± .02	1.89 ± .02	.90	2.03 ± .02	2.01 ± .03[c]
20m Sprint (s)	7.18*	3.54 ± .02	3.31 ± .03	.40	3.56 ± .03	3.54 ± .04[c]
Hexagon Agility (s)	.24	11.84 ± .25[a]	11.65 ± .48[h]	.26	11.55 ± .27[b]	12.20 ± .45[g]
FAT (s)	.13	2.32 ± .03[d]	2.28 ± .03[e]	9.42*	2.40 ± .02[a]	2.31 ± .03[f]
BAT (s)	.10	2.43 ± .03[d]	2.37 ± .03[e]	1.07	2.46 ± .02[a]	2.43 ± .03[f]
CMJ (cm)	4.69*	40.69 ± .84	48.33 ± 1.20	.43	40.65 ± 1.06	41.62 ± 1.64[c]
SJ (cm)	.80	38.5 ± 1.05[d]	42.00 ± .76[e]	.01	36.71 ± 1.31[a]	36.57 ± 2.05[f]
FHMBT (m)	22.48*	11.43 ± .22	15.02 ± .31	.48	11.07 ± .21	10.99 ± .32[c]
BHMBT (m)	24.51*	10.80 ± .24	14.69 ± .34	.31	10.42 ± .20	10.29 ± .30[c]
OHMBT (m)	10.92*	8.41 ± .23	11.17 ± .33	3.42**	8.13 ± .21	8.51 ± .33[c]
YYIRT (m)	.00	1583 ± 75.53[d]	1720 ± 83.06[e]	.02	1583.33 ± 55.02[a]	1120 ± 86.32[f]

n^a = 17, n^b =14, n^c =13, n^d =12, n^e =10, n^f =7, n^g = 6, n^h = 5

Significant difference between maturity groups ($p< 0.05$; ** $p< 0.10$)*

RHGS: Right Hand Grip Strength, LHGS: Left Hand Grip Strength, FAT: Forehand Agility Test, BAT: Backhand Agility Test, CMJ: Countermovement Jump, SJ: Squat Jump, FHMBT: Forehand Medicine Ball Throw, BHMBT: Backhand Medicine Ball Throw, OHBMT: Overhead Medicine Ball Throw, YYIRT: Yo-Yo Intermittent Recovery Test.

Image 1. Start and finish position of the Forehand Medicine Ball Throw

Image 2. Start and pre-release position of the Overhead Medicine Ball Throw